Potential Effects of Nutrient Control Measures in the Clark Fork Basin on Resident Fisheries

Prepared by
Ken Knudson
Ecological Resource Consulting
Helena, MT

Prepared for
The Montana Department of Health and Environmental Sciences
Helena, MT

January 1992

Table of Contents

List of Figures

List of Tables

I. Introduction

Concern about excessive accumulations of attached algae (periphyton) in the Clark Fork River has prompted recent efforts to reduce the river's concentrations of nutrients, the chemical compounds necessary for the growth of these aquatic plants. Phosphorus and, less often, nitrogen compounds are the nutrients that usually limit periphyton growth or densities in surface waters (Vallentyne, 1974). Wastewater treatment improvements and the banning of phosphorus detergents have substantially reduced the phosphorus concentrations at two major point source discharges in the basin, the Stone Container Corporation's pulp and paper mill and the city of Missoula's wastewater treatment plant. The decrease in phosphorus concentrations in the river, resulting from these waste-reduction efforts, should result in lower periphyton production and/or biomass, especially during summer. There should also be less impact to water clarity during autumn, when cooler water temperatures cause attached algae to die, decompose and become suspended in the water column. The amount of surface foam, also caused by decaying periphyton, should be reduced. Finally, the respiration of the river's reduced algal community should be less, leaving more dissolved oxygen in the river for trout and aquatic invertebrates.

The nutrient reduction efforts achieved thus far in the basin will hopefully improve the aesthetics and dissolved oxygen conditions of the Clark Fork below Missoula. However, when

attempting to regulate the instream concentrations of nutrients, decision-makers can also be faced with concerns regarding too little as well as too much. Unlike most other potential pollutants like heavy metals, pesticides or organic chemicals, where reductions in instream concentrations result in increasingly better living conditions for aquatic life, it is essential that certain levels of nutrients remain instream to support the fundamental food chain requirements of aquatic ecosystems. If instream concentrations of nitrogen or phosphorus compounds fall below critical levels, primary productivity rates and ultimately fish production could suffer.

Lake fertilization studies in Canada have clearly demonstrated the benefits of adding nitrogen and phosphorus compounds to waters with low ambient concentrations of these nutrients (Hyatt and Stockner, 1985). Increased phosphorus inputs to these lakes resulted in increased densities of suspended algae (phytoplankton), which in turn lead to increased zooplankton and sockeye salmon biomass.

Evaluations of stream ecosystems in the Appalachians also suggest that trout production is directly related to instream nutrient regimes (Cada, et. al., 1987; Neves and Pardue, 1983). However, nutrient:fish production correlations for these streams were not as precise or detailed as was reported for the lake studies. Furthermore, detailed nutrient monitoring has not been conducted in combination with long-term fish production studies

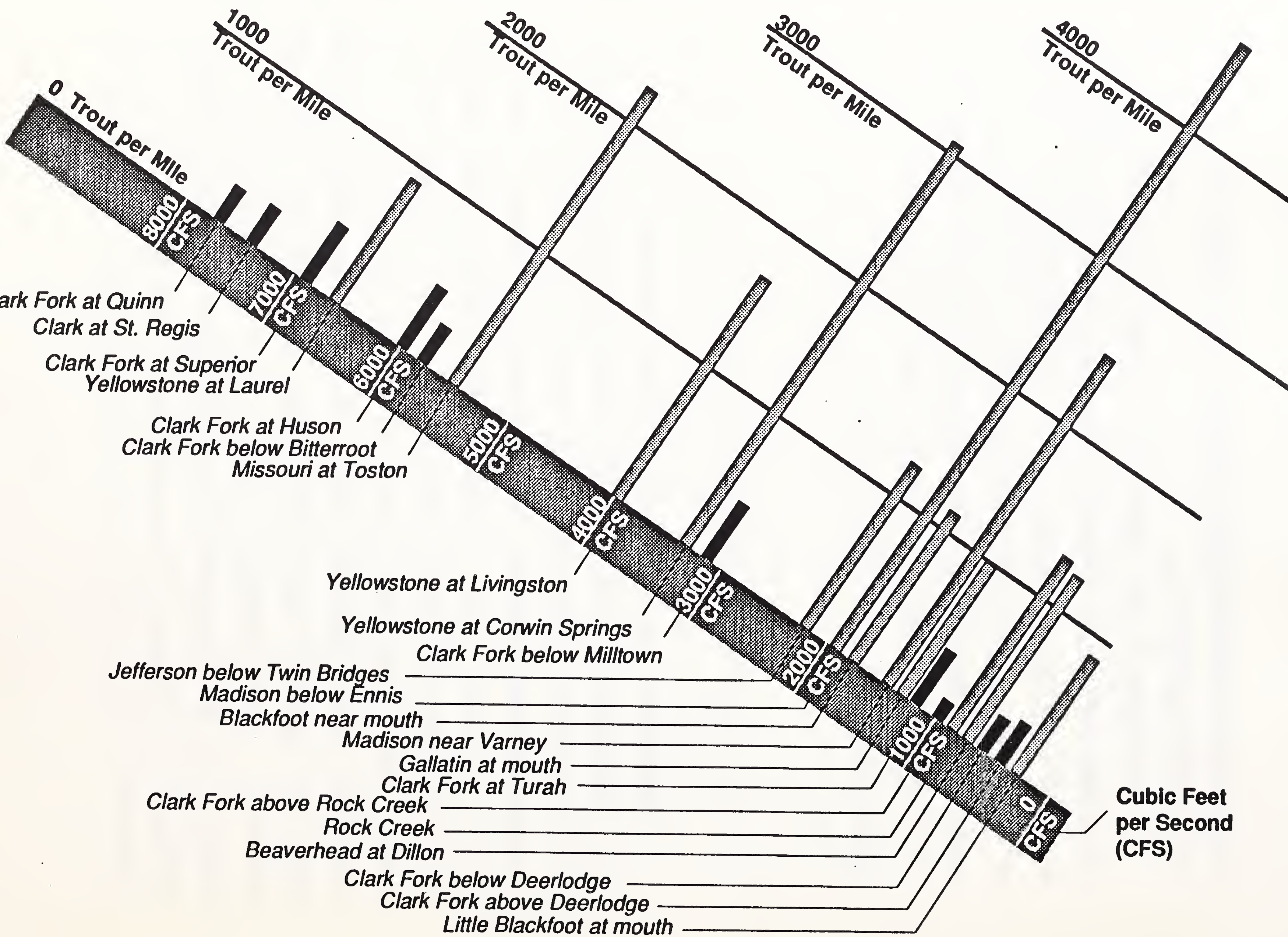
on any stream ecosystem where nutrient inputs have been significantly reduced.

The purpose of this paper is to attempt to investigate how additional changes in the Clark Fork River's nutrient regime might potentially affect the river's aquatic community. Emphasis will be placed on how differing nutrient levels could potentially impact trout populations. Consequently, along with changes in nutrient levels, other factors that are limiting the river's trout fishery will also be discussed.

II. Trout Populations in Montana Rivers

Since 1972, the Montana Department of Fish, Wildlife and Parks has routinely estimated trout population densities within five sections of the upper Clark Fork River; e.g. below Warm Springs and Deer Lodge and near Phosphate/Gold Creek, Bearmouth/Bonita and Turah (Peters, 1981 and 1985). Hadley (1989) expanded upon this data coverage by conducting estimates throughout the reach of the Clark Fork from its origin near Warm Springs to the confluence of the Blackfoot River. Below Milltown Dam, estimates have been conducted since 1979 (Peters, 1985 and Berg, 1988, 1989 and 1990). Below Missoula to the confluence of the Flathead River, trout densities have been estimated within six sections, starting in 1984 (op. cit.). The data for the Clark Fork displayed on Figure 1 are trout density averages for all years of

Figure 1. Trout Population Densities (trout per mile) and the Average Annual Discharge (cubic feet per second) in Sections of the Clark Fork River versus otherMontana Rivers.



record at each section or river reach. The data for the other trout streams was retrieved from the Montana Rivers Interagency Data Base in the spring of 1991. Trout densities for these rivers are based upon one to three years of record spanning 1977-1985.

The Clark Fork River is the poor cousin of Montana trout streams. As can be seen on Figure 1, trout densities in the river are much lower than are found in other Montana streams. Except for a short river section near Warm Springs, trout densities above the Little Blackfoot River average about 250 trout/mile. From the Little Blackfoot to the confluence of Rock Creek, these numbers are even lower, ranging from 50-200 trout/mile. Below Rock Creek to Missoula, trout densities improve somewhat to values around 400 trout/mile. This level is roughly maintained from Missoula to the confluence of the Flathead, with the highest section average being at Huson (457/mile) and the lowest being Quinn, just above the Flathead (253/mile).

By comparison, all of the Montana rivers that were reviewed for this report had much higher trout population densities, with the Madison River below Ennis having the highest value at 4666/mile. Even the tributaries to the Clark Fork that are shown on Figure 1; ie. the Little Blackfoot, Rock Creek and the Blackfoot, support much better trout densities than are found in similar-sized sections of the Clark Fork.

The Clark Fork River suffers from a myriad of water quality, habitat and water quantity impacts that likely contribute to the river's depressed trout fishery. One often cited impact is an overabundance of nutrients and resulting nuisance levels of periphyton.

III. Nutrient Levels in the Clark Fork River

In recent years, the Clark Fork River has been one of the most intensively monitored rivers in the northern Rockies. Since 1984, the Montana Department of Health and Environmental Sciences, Water Quality Bureau, has been routinely monitoring water quality variables on the river and its tributaries from Butte to the Idaho border. Beginning in 1988, a three-year assessment of water pollution problems in the Clark Fork-Lake Pend Oreille Basin was established. During this assessment, fifty-one surface water stations in the basin were monitored for nutrients fifteen times per year (Ingman, 1991). These stations were typically monitored twice per month during runoff (April through June) and once per month during the rest of the year.

The following discussion utilizes instream nutrient data collected by the Water Quality Bureau during fiscal years 1988-1990. Fourteen mainstem stations, from Warm Springs to the river's confluence with the Flathead River are discussed. The

locations of these stations are listed in Table 1 and displayed on Figure 2.

The distance from sampling Station 7 (Warm Springs) to Station 25 (above the Flathead) is roughly 250 river miles. Between these stations, the river's average annual discharge increases from about 100 cubic feet per second (cfs) to 7500 cfs. Average nutrient concentrations also vary considerably between stations. In the analysis that follows, these station averages are compared to several criteria and/or instream concentrations which have been reported to limit nuisance algal conditions in flowing waters.

To control excessive development of attached algae, and to prevent accelerated eutrophication of lakes, the U.S. EPA (1986) has recommended an instream criterion of 50 ug/l for total phosphorus. Bothwell (1988) and Watson (1990) have reported that the maximum sustainable standing crop or <u>biomass</u> of periphyton in artificial streams was reached when soluble reactive phosphorus (SRP) concentrations approached 30 ug/l. Bothwell (1989) found that instream SRP concentrations must be above 1 ug/l to saturate productivity or <u>growth rates</u> of attached algae.

The U.S. EPA instream criterion for total soluble inorganic nitrogen (TSIN) is 1000 ug/l. Watson (1990) reported that TSIN levels above 250 ug/l are in excess of those needed to sustain maximum accumulations of attached algae. Regarding instream bioavailable nitrogen levels necessary to saturate periphyton

Table 1. Locations of Clark Fork River Water Quality Monitoring Stations Reviewed in This Report

Station Number	Location
7	At Warm Springs
8	Near Dempsey
9	Above Deer Lodge
10	Above Little Blackfoot River
11	At Gold Creek
12	At Bonita
13	At Turah
15.5	Above Missoula
18	Below Missoula WWTP
20	At Harper Bridge
22	At Huson
23	Near Alberton
24	At Superior
25	Above Flathead River

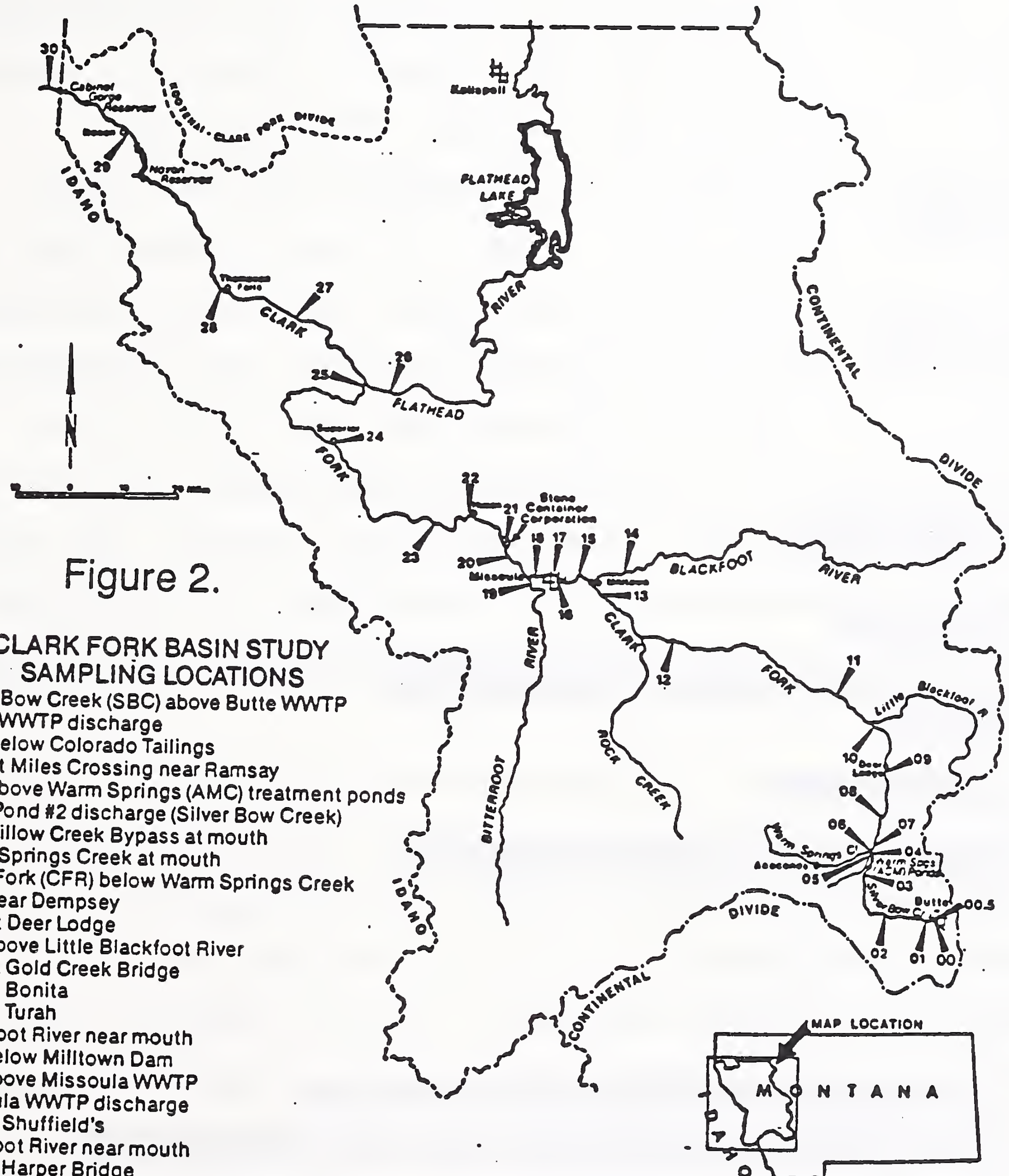


Figure 2.

CLARK FORK BASIN STUDY SAMPLING LOCATIONS

00 Silver Bow Creek (SBC) above Butte WWTP
00.5 Butte WWTP discharge
01 SBC below Colorado Tailings
02 SBC at Miles Crossing near Ramsay
03 SBC above Warm Springs (AMC) treatment ponds
04 AMC Pond #2 discharge (Silver Bow Creek)
05 Mill-Willow Creek Bypass at mouth
06 Warm Springs Creek at mouth
07 Clark Fork (CFR) below Warm Springs Creek
08 CFR near Dempsey
09 CFR at Deer Lodge
10 CFR above Little Blackfoot River
11 CFR at Gold Creek Bridge
12 CFR at Bonita
13 CFR at Turah
14 Blackfoot River near mouth
15 CFR below Milltown Dam
16 CFR above Missoula WWTP
17 Missoula WWTP discharge
18 CFR at Shuffield's
19 Bitterroot River near mouth
20 CFR at Harper Bridge
21 Stone Container Corporation wastewater discharge
22 CFR at Huson
23 CFR near Alberton
24 CFR at Superior
25 CFR above Flathead River
26 Flathead River near mouth
27 CFR above Thompson Falls Reservoir
28 CFR below Thompson Falls Dam
29 CFR below Noxon Rapids Dam
30 CFR below Cabinet Gorge Dam

growth rates, Bothwell (1989) has suggested that TSIN concentrations need to be above 50 ug/l.

The EPA total phosphorus criterion of 50 ug/l was regularly exceeded in the Clark Fork above Missoula (Figure 3). Exceedence of this criterion was most frequent (85% of the total measurements) at Station 10, downstream of the Deer Lodge wastewater treatment plant (WWTP). At stations below Rock Creek, total phosphorus concentrations greater than 50 ug/l were present during less than 25% of the sampling dates, with one exception. At Station 18, below the Missoula WWTP, this criterion was exceeded during 57% of the instream measurements taken in fiscal years (FY) 1988-1990. It should be noted, however, that this frequency of exceedence was only 13% at Station 18 during FY 1990, the first year of the phosphorus detergent ban in Missoula County.

The percentage of samples from the Clark Fork stations with SRP concentrations greater than 30 ug/l, the level needed to sustain maximum periphyton biomass, are displayed on Figure 4. These data are similar to, but less pronounced than, the information for total phosphorus. During FY 1988-90, the river from the Deer Lodge WWTP to Rock Creek contained the highest SRP concentrations. Station 10 was again the most degraded, with 47% of its SRP measurements exceeding 30 ug/l. The river below Rock Creek rarely contained SRP concentrations above this level, except at Station 18, where this value was exceeded 45% of the time during the three years of record. However, during FY 1990,

Figure 3 . Pecentage of Samples Exceeding the U.S. EPA Instream Criteria for Total Phosphorus (50 micrograms/liter) at Fourteen Stations on the Clark Fork River in Fiscal Years 1988, 1989 and 1990.

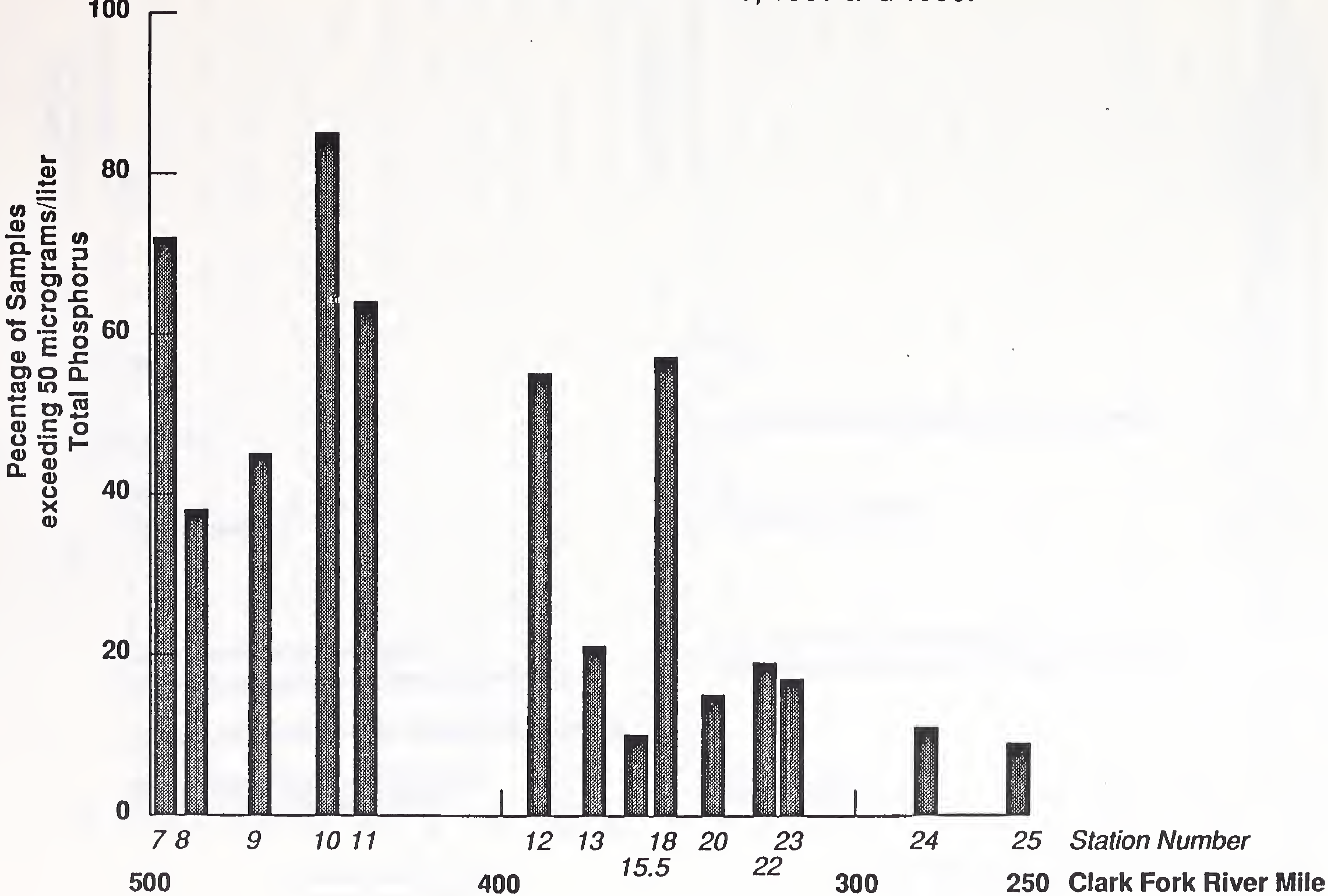
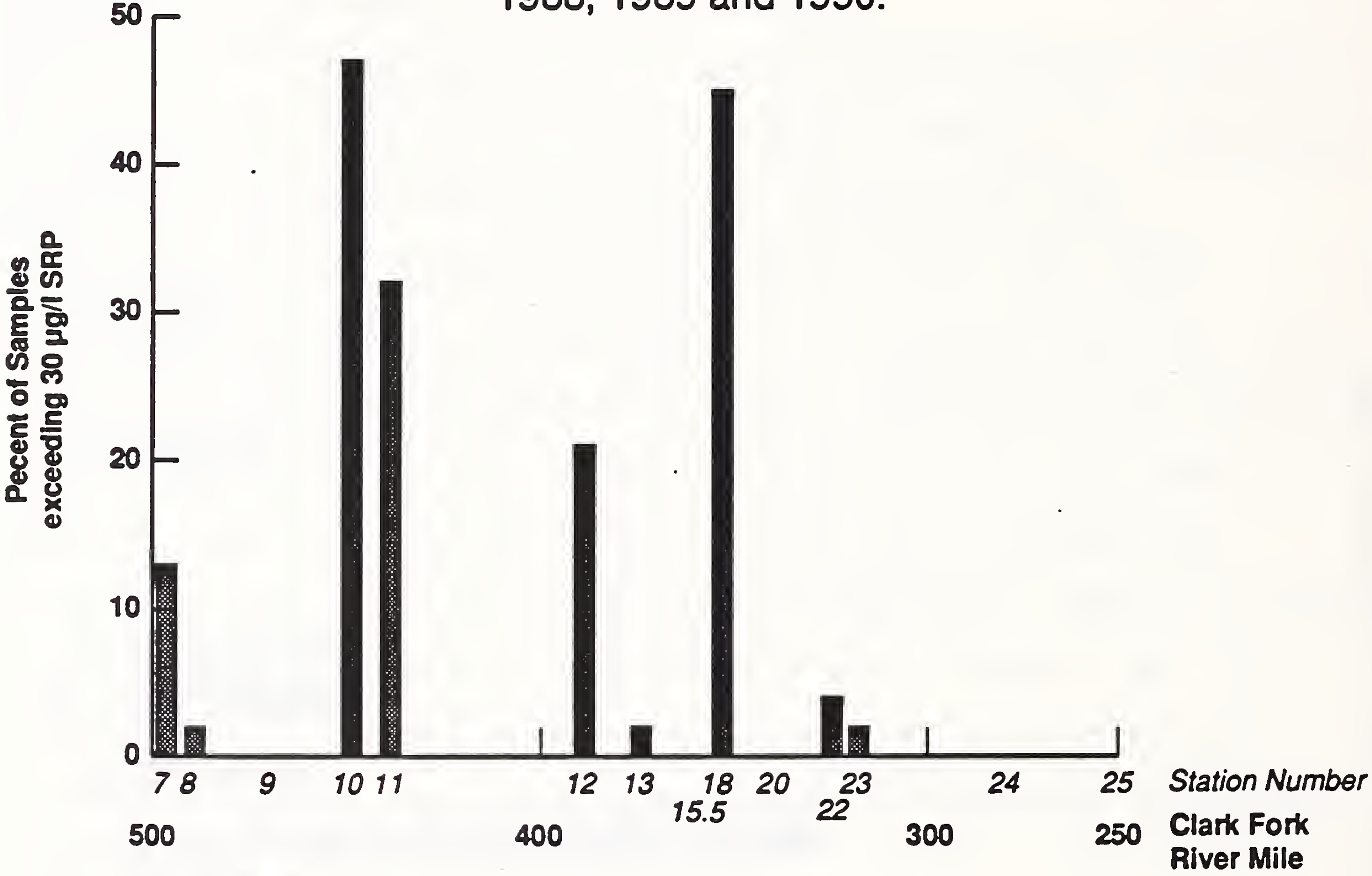
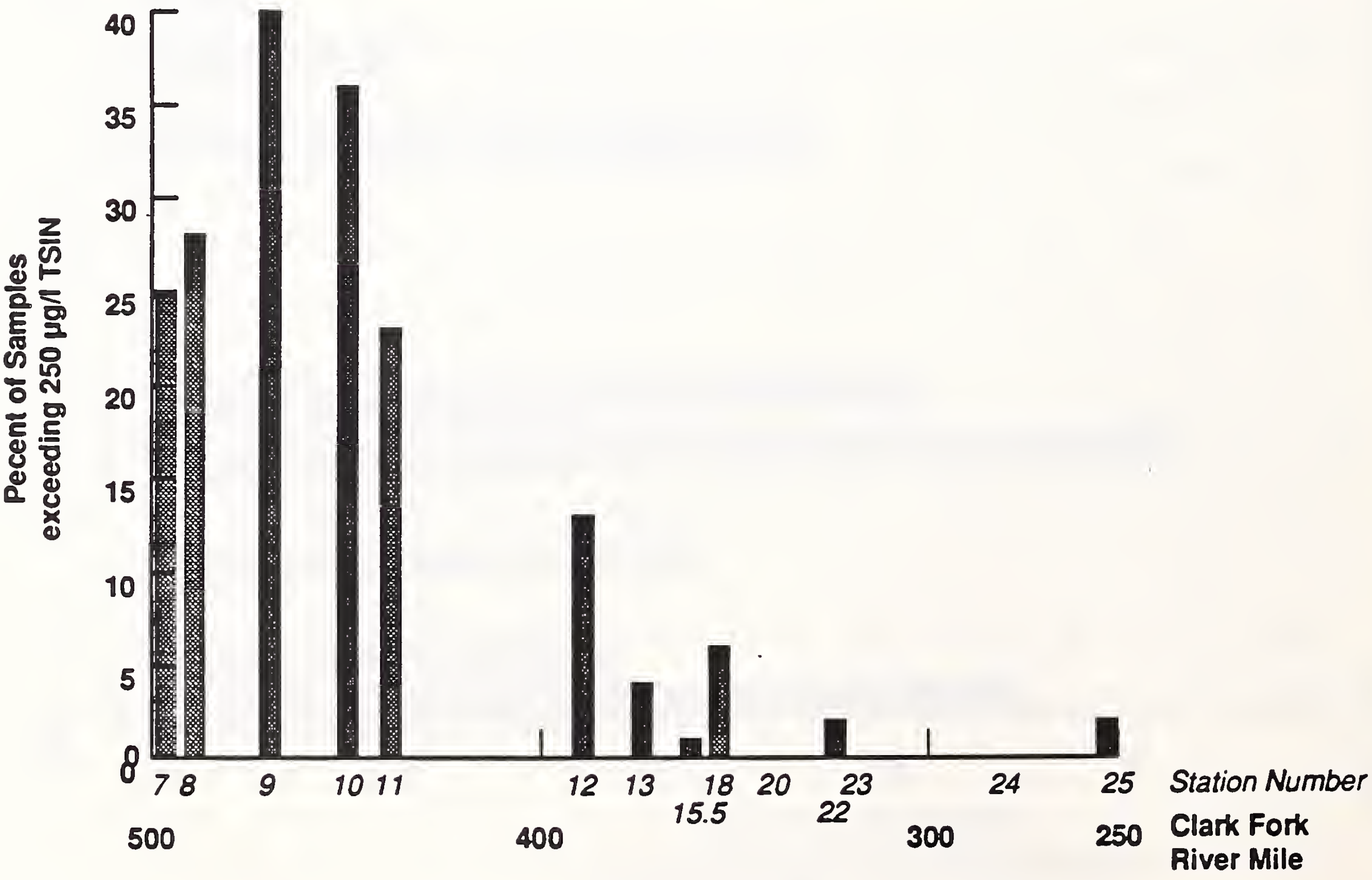


Figure 4 . Pecentage of Samples Exceeding Instream Concentrations Needed to Sustain Maximum Periphyton Biomass (30 µg/l SRP and 250 µg/l TSIN) at Fourteen Stations on the Clark Fork River in Fiscal Years 1988, 1989 and 1990.





concentrations greater than 30 ug/l only occurred 12% of the time at this station.

The instream criterion of 1000 ug/l for TSIN was never exceeded at any of the Clark Fork River mainstem monitoring stations during FY 1988-1990. This is a significant contrast to the river's status regarding the total phosphorus criterion which, as just shown, was exceeded at all of the stations above the Flathead River at least some of the time.

The percentage of TSIN samples exceeding 250 ug/l, the concentration reported to sustain maximum periphyton biomass, are also shown on Figure 4. The upper river again contained the highest instream levels. Station 9, above Deer Lodge, had the most frequent occurrence of values greater than 250 ug/l (40%).

The elevated TSIN levels in the upper river are caused by non-point sources. Much of the river's riparian zone and adjoining, low-elevation benchlands receive intense agricultural use. Thousands of cattle are wintered near the river in areas with shallow ground water and/or highly permeable soils. Nitrogen compounds, produced during biological decomposition of the cattle's organic waste, enter the river via surface runoff or through shallow aquifers draining into the Clark Fork above Deer Lodge. Additional non-point contamination is caused by irrigation return flows and snowmelt and precipitation-related runoff from roads, logging sites and overgrazed rangeland. The Warm Springs Ponds, which for decades have served as settling ponds for Butte's domestic wastes, also likely contribute TSIN to

the Deer Lodge Valley aquifer, and ultimately, to the Clark Fork River.

The relative contribution of, or loading from, the above non-point sources to the river is unknown, but their combined impact is significant. As can be seen in Table 2, during FY 1988 and 1990 monitoring, about 35 tons/year of TSIN entered the Clark Fork River between Warm Springs (Station 7) and just above Deer Lodge (Station 9). By comparison, the Deer Lodge WWTP contributed 11.3 tons/year to the river during FY 1990 (Ingman, 1991).

From Station 7 to Station 9, the river's mean discharge doubles, but its TSIN load nearly triples. From Station 9 to Turah (Station 13) the river's TSIN load remains essentially the same (+/-20%), while its volume increases significantly. Essentially, during FY 1988 and 1990, the Clark Fork River in the Deer Lodge Valley had the same TSIN load as at Turah, where its mean annual discharge is around five times larger.

Whether analyzed from an instream concentration or loading viewpoint, non-point sources in the Deer Lodge Valley deliver relatively large quantities of TSIN to the river. Little wonder that the Clark Fork's densest algal accumulations start to occur after the Deer Lodge WWTP discharge enters the river. For, although the Deer Lodge WWTP is responsible for only a relatively small amount of the total TSIN load to the Clark Fork above the Little Blackfoot River, its influence on SRP loading is

Table 2. Total Soluble Inorganic Nitrogen Loads (tons/year) and Average Annual Stream Discharge Rates (cubic feet/second) for Stations in the Upper Clark Fork River

FY 1990

Station	Mean Discharge	TSIN Load
7	89	14.1
8	128	26.3
9	188	49.7
10	205	50.5
11	412	48.1
12	685	55.1
13	1152	57.6

FY 1988

Station	Mean Discharge	TSIN Load
7	88	12.0
8	105	13.2
9	173	46.6
10	181	46.0
11	295	51.8
12	455	37.4
13	832	40.8

significant. During FY 1990, the SRP load from the Deer Lodge facility (3.8 tons/year) was over twice the value for the river at Station 9 (1.6 tons/year).

Below Rock Creek, instream TSIN concentrations were rarely above 250 ug/l. Even below the Missoula WWTP, concentrations exceeding this level were found during only 6% of the sampling episodes. While the TSIN load from the Missoula WWTP is significant, 149 tons during FY 1990 (Ingman, 1991), the average annual discharge of the Clark Fork River at Missoula is also about fifteen times larger than at Deer Lodge. Over half of the river's volume at Missoula is provided by the Blackfoot River, which contributed only 77 tons of TSIN to the Clark Fork during FY 1990. As a result, instream TSIN concentrations rarely exceeded 250 ug/l.

The three-year average and summer (July-September) average concentrations for SRP at the fourteen Clark Fork River stations are displayed on Figure 5. At Station 7 (Warm Springs), the river reach from Deer Lodge to Rock Creek and at Station 18 (below the Missoula WWTP), yearly averages were 2 to 3 times higher that anywhere else on the river. During summer, SRP averages were higher than the yearly averages at all of the stations above Rock Creek and at Station 18.

These elevated summer SRP averages in the upper river and below the Missoula WWTP are opposite to the river's TSIN regime. As shown on Figure 6, summer averages for TSIN were considerably lower than the year-round averages at all stations. The most

Figure 5. Soluble Reactive Phosphorus concentrations at fourteen stations on the Clark Fork River. Data is for fiscal years 1988, 1989 and 1990.

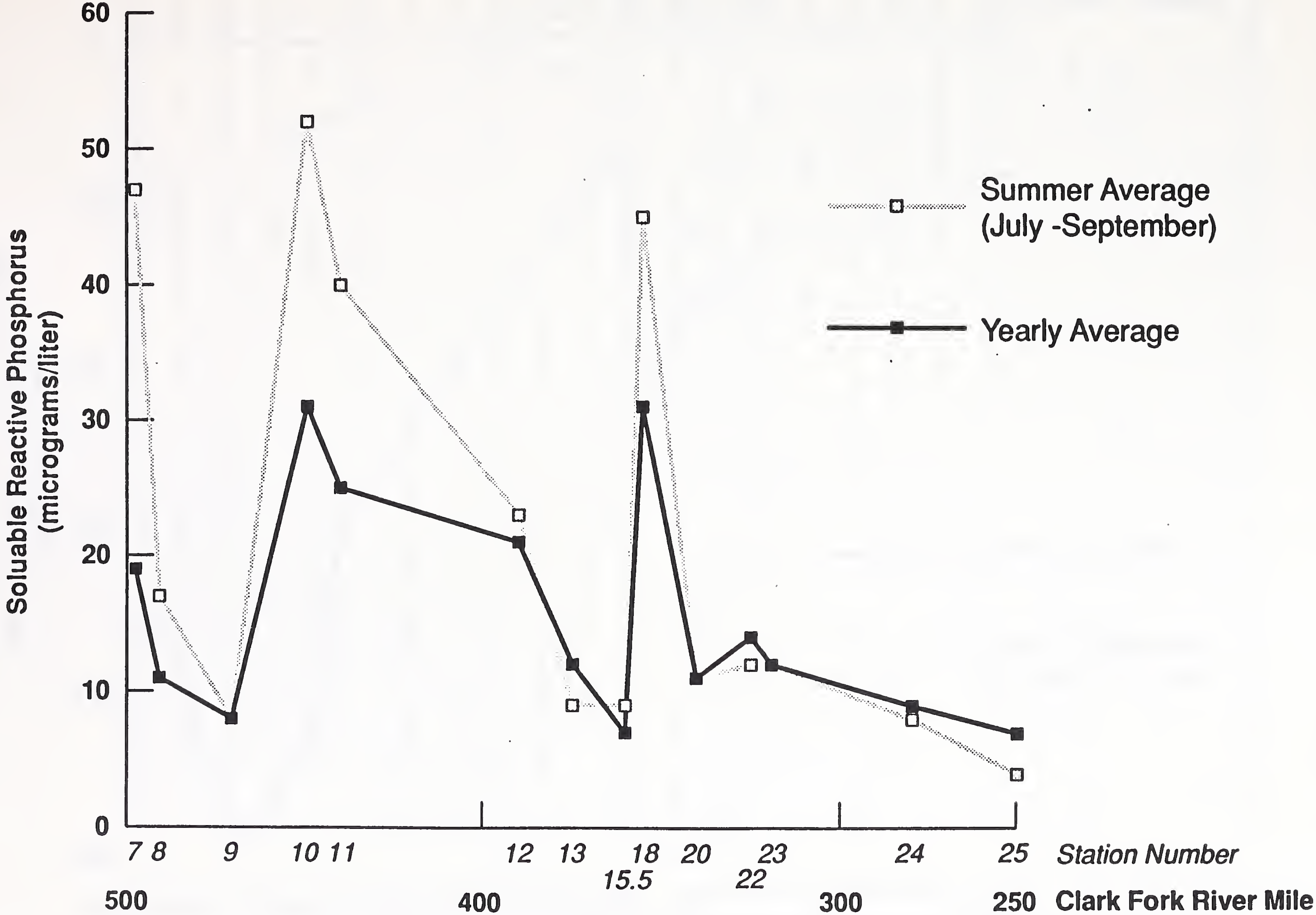
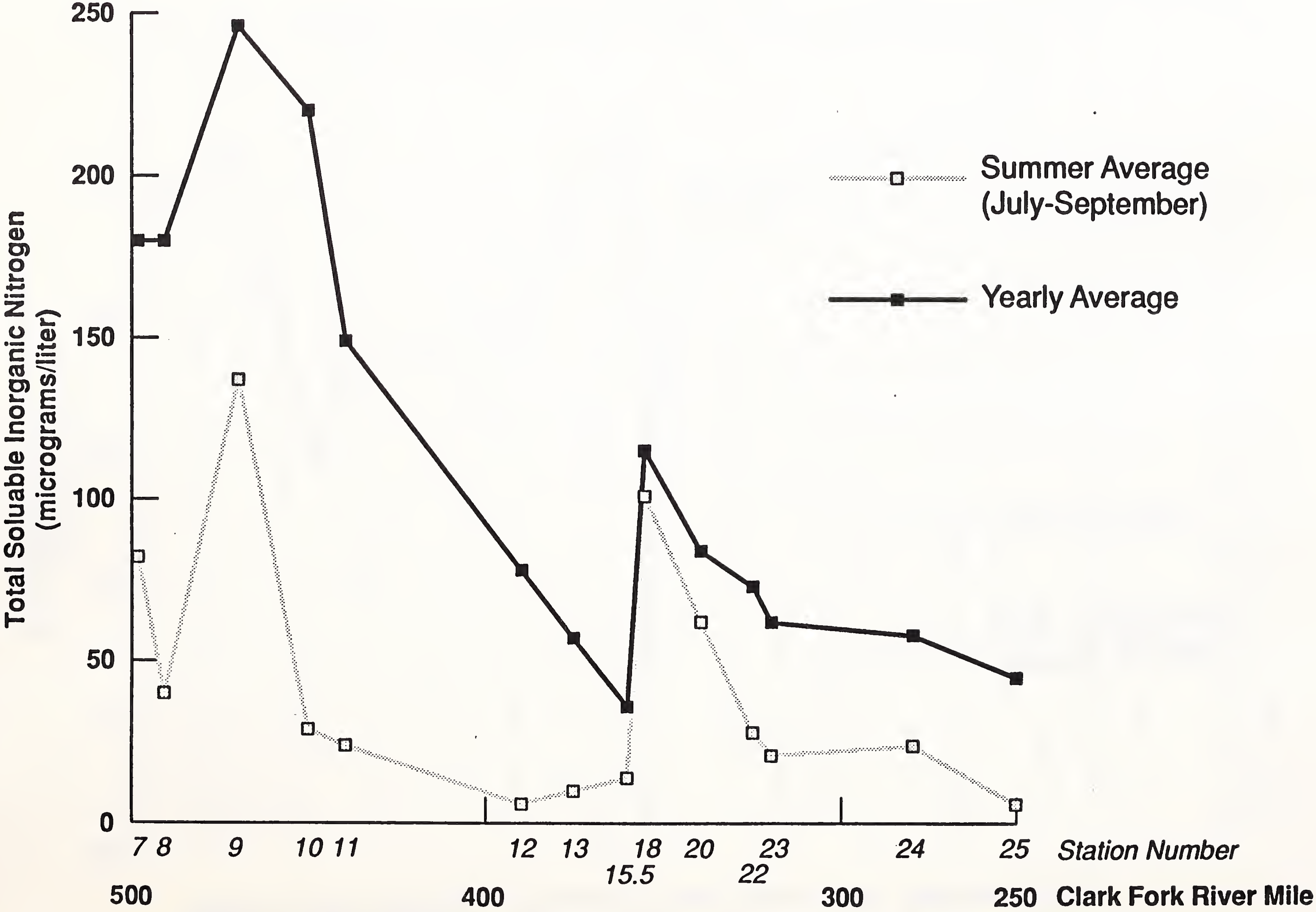


Figure 6. Total Soluble Inorganic Nitrogen (or dissolved nitrate plus nitrate plus ammonia) at fourteen stations on the Clark Fork River. Data is for fiscal years 1988, 1989 and 1990.



dramatic difference between summer versus yearly averages was at Station 10. Here, the year-round TSIN average (220 ug/l) was about 7.5 times higher than the summer average (29 ug/l).

Because of warmer water temperatures and longer photoperiods, summer is when most nuisance algae problems occur. SRP and total phosphorus concentrations in the river above Rock Creek during summer are frequently at or above levels that can sustain maximum accumulations of attached periphyton.

With the phosphorus detergent ban in place, summer SRP concentrations at Station 18 dropped from the three-year average of 44 ug/l shown in Figure 5 to 21 ug/l during the FY 1990 monitoring. This is a substantial reduction in bioavailable phosphorus concentrations--from 14 ug/l above the maximum biomass accumulation threshold to 9 ug/l below this value. Downstream of Station 18 to St. Regis (Station 24), summer SRP concentrations were also generally less during FY 1991 (Table 3). The difference in average concentrations between the three-year average versus FY 1990 was most apparent at Station 18 (53%). FY 1990 summer averages were also 13% to 27% lower at stations 20-24. At Station 25, however, the FY 1990 SRP summer average was 25% higher than during FY 1988-90.

The reduced summer SRP concentrations during FY 1990 produced conditions likely to reduce periphyton biomass in the river between Missoula and the confluence of the Bitterroot River. Yet, attributing these lower average concentrations solely to the phosphorus ban is not completely justifiable at

Table 3. Differences in Average Summer SRP Concentrations: FY 1988-90 Compared to FY 1990 Data at Stations on the Clark Fork River

Station	3-Year Ave. (ug/l)	FY 1990 Ave. (ug/l)	Difference between 3-yr vs. FY 1990 Aves. (ug/l)	(% change)
7	47	22	-25	-53%
8	17	8	-9	-53%
9	8	4	-4	-50%
10	52	32	-12	-38%
11	40	26	-14	-35%
12	23	26	+3	+13%
13	9	11	+2	+22%
15.5	9	11	-3	-33%
18	45	21	-24	-53%
20	11	8	-3	-27%
22	12	11	-1	-13%
23	12	9	-3	-25%
24	8	6	-2	-25%
25	4	5	+1	+25%

this time. One year of post-ban monitoring is not sufficient to account for annual variations in the nutrient regime of the river, particularly since higher streamflows were present basin-wide during FY 1990. As a result, average summer SRP concentrations were also generally lower during FY 1990 in the upper river. At stations above Gold Creek during FY 1990, summer SRP averages were 35 to 53% less than the three-year summer average. Above Missoula, only stations 12 (Bonita) and 13 (Turah) had higher summer values; 13% and 22% respectively.

The discussion thus far has focused on nutrient levels that can potentially limit the occurrence of nuisance accumulations of attached algae. On the other hand, nutrient management strategies for rivers ideally would eliminate the use-impairment caused by the algae while maintaining an acceptable level of primary productivity needed to sustain a healthy fishery.

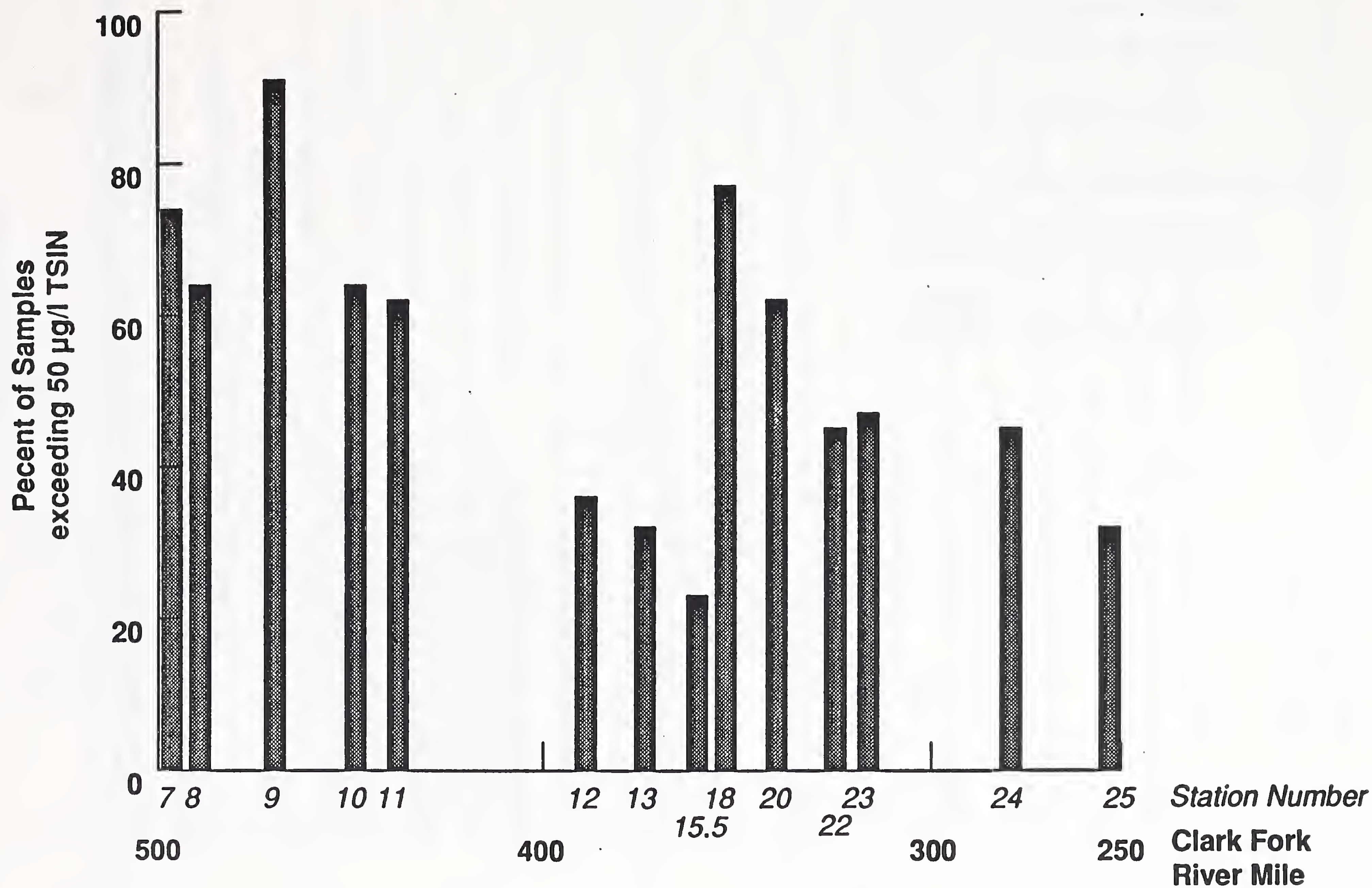
Regarding SRP, instream concentrations on the Clark Fork River mainstem above the Flathead River have rarely fallen below 1 ug/l, the instream level needed to saturate the primary productivity or growth rate of attached algae (Bothwell, 1989). In fact, during FY 1990, 100% of the measurements at stations 18-25 were above this value, with the lowest three-year SRP average being 7 ug/l at Station 25.

In contrast, TSIN levels throughout the river were quite often below the 50 ug/l value that Bothwell (1989) feels is

necessary to saturate algal growth rates. Figure 7 displays the percentage of TSIN measurements that exceeded 50 ug/l at fourteen stations on the Clark Fork during FY 1988-90. None of the stations had TSIN concentrations that exceeded 50 ug/l during 100% of the sampling episodes. Station 9 had the highest percentage of measurements above this value (91%). But, at seven of the fourteen stations, TSIN concentrations were less than 50 ug/l during over half of the sampling dates. Measurements greater than this level only occurred 32% of the time at Station 25 and 23% of the time at State 15.5. Furthermore, the majority of these relatively low TSIN concentrations occurred during summer.

If Bothwell's suggested growth-saturation value for TSIN is applicable to the Clark Fork, present instream concentrations of this nutrient could already be limiting algal productivity rates in the river during significant portions of the year. However, as will be discussed in the next section of this report, other notable Montana trout streams also often contain relatively low concentrations of bioavailable nitrogen, especially during summer. Conversely, regarding excessive nutrient levels, some of these rivers have higher average concentrations of certain nutrients than were present on the Clark Fork during FY 1988-90. By comparing the nutrient regime of the Clark Fork to other Montana trout rivers, further insight into any potential relationship between instream nutrient levels and trout population densities can be gained.

Figure 7 . Pecentage of Samples Where Instream TSIN Concentrations Were Above Levels Needed to Maximize or Saturate Periphyton Primary Productivity Rates (50 µg/l) at Fourteen Stations on the Clark Fork River in Fiscal Years 1988, 1989 and 1990.



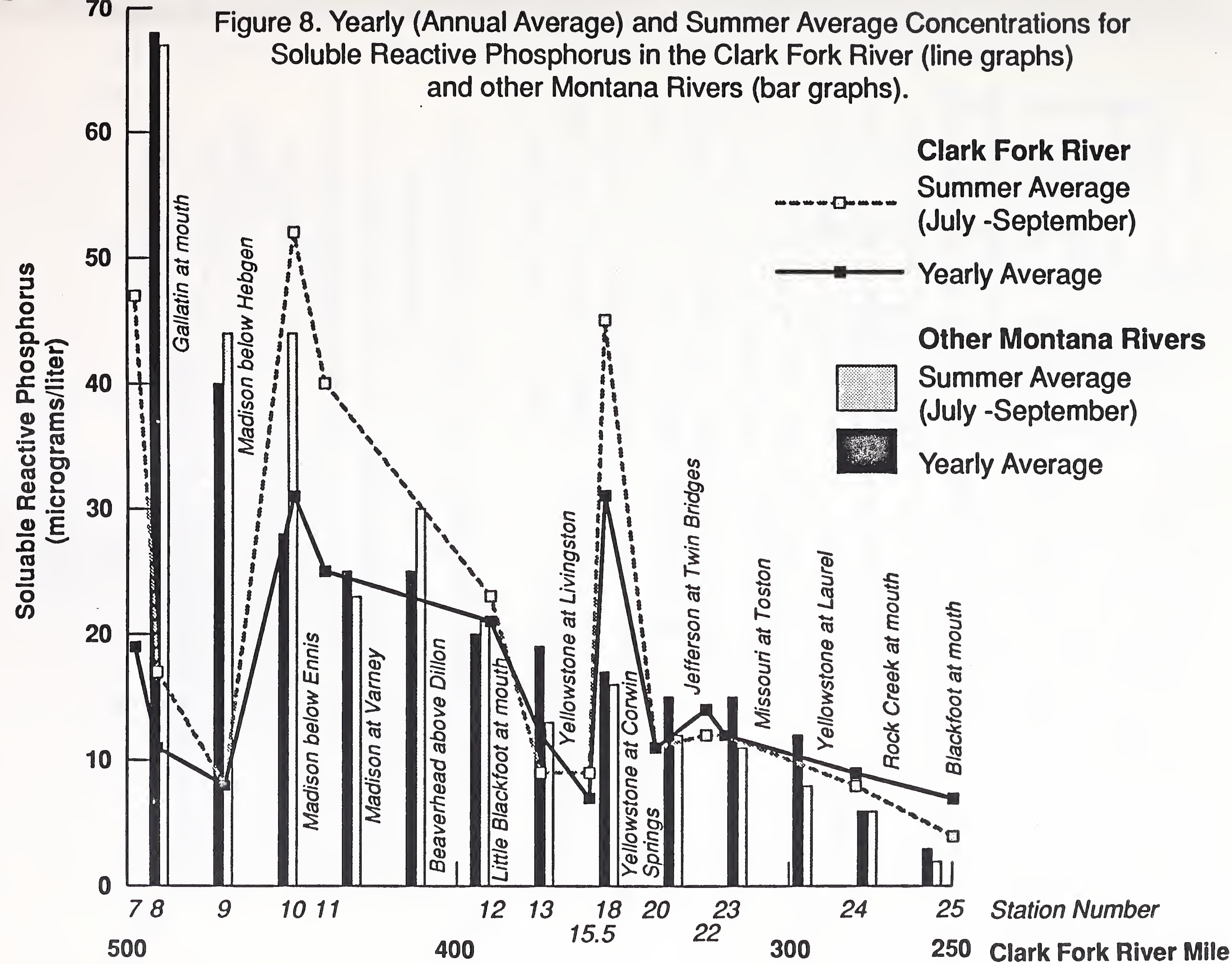
IV. Nutrient Levels in the Clark Fork Compared to Other Montana Trout Streams

In the spring of 1991, water quality measurements for other Montana trout streams were retrieved from the U.S. EPA's STORET Data Base, which contains most of the surface water quality information collected by state and federal agencies. None of these rivers were found to have a nutrient data base that is spatially or temporally comparable to that of the Clark Fork. Only fourteen water quality stations, including three that are tributaries to the Clark Fork, were ultimately selected to be used in this report. These stations were selected utilizing two basic guidelines: (1) they were sampled approximately monthly for at least one year and/or quarterly for over two years; and (2) they were located close to a historical trout population density section.

The period of record and sampling frequency for these stations varies considerably. Several years of data are available for the Beaverhead at Dillon, the Missouri at Toston and the Yellowstone at Laurel, while stations on the Gallatin and Madison have only about one year of usable data. Appendix A contains the periods of record and sampling frequencies for all of the comparative rivers discussed in this report.

Figure 8 compares yearly and summer average concentrations of SRP in the Clark Fork (the data shown earlier on Figure 5) to averages for other Montana trout streams. The Gallatin River had

Figure 8. Yearly (Annual Average) and Summer Average Concentrations for Soluble Reactive Phosphorus in the Clark Fork River (line graphs) and other Montana Rivers (bar graphs).

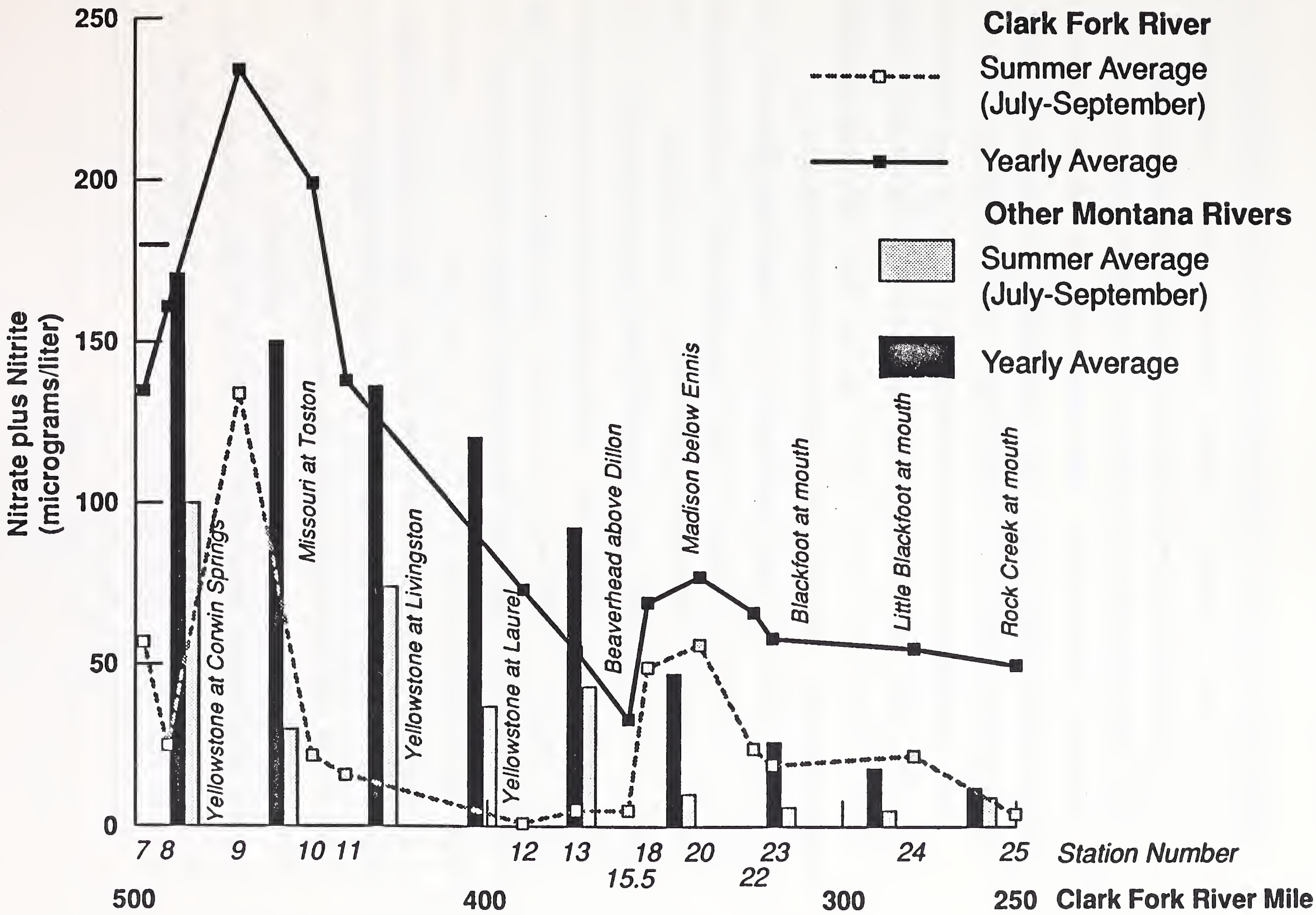


the highest yearly and summer values at 68 ug/l and 67 ug/l, respectively. The Madison below Hebgen had the second highest year-round SRP average (40 ug/l). No station on the Clark Fork had a yearly average that was even half of that found on the Gallatin. However, the summer SRP averages in the Clark Fork River at Warm Springs, below Deer Lodge, at Gold Creek and below Missoula were similar to the summer values for the Madison below Hebgen and Ennis, which had the second and third highest summer averages for the comparative rivers. All of the remaining Clark Fork stations had SRP averages that were similar in magnitude to one of the other Montana trout streams. For example, SRP concentrations in the river from the Bitterroot to St. Regis were comparable to the Yellowstone at Laurel, the Missouri at Toston and the Jefferson at Twin Bridges; the Clark Fork at Bonita was similar to the Little Blackfoot and the Beaverhead at Dillon, etc. No station on the Clark Fork, however, had yearly or summer SRP average concentrations as low as values for the Blackfoot River or Rock Creek.

Figure 9 compares yearly and summer average concentrations of nitrate plus nitrite in the Clark Fork to other Montana rivers. Nitrate plus nitrite, rather than TSIN, was used in this comparison because ammonia analyses were not conducted frequently enough on the other rivers to allow computation of the latter.

Yearly average nitrate/nitrite concentrations on the Clark Fork from above Deer Lodge to above the Little Blackfoot were higher than were found on any of the comparative rivers. Yearly

Figure 9. Yearly (Annual Average) and Summer Average Concentrations for Nitrate plus Nitrate in the Clark Fork River (line graphs) versus other Montana Rivers (bar graphs).



averages for stations on the Clark Fork below Missoula to the Flathead ranged between values for the Beaverhead at Dillon (92 ug/l) and the Madison below Ennis (47 ug/l); averages at Warm Springs and Gold Creek were similar to the Yellowstone at Livingston (135-138 ug/l). The lowest yearly nitrate/nitrite average on the Clark Fork, the station above Missoula, was close to the average value for the Blackfoot (33 versus 26 ug/l).

The summer nitrate/nitrite average above Deer Lodge, 134 ug/l, was the highest found on any of the rivers reviewed in this report. The Yellowstone at Corwin Springs had the second highest summer average (100 ug/l), followed by the Yellowstone at Livingston (74 ug/l) and the Clark Fork at Warm Springs (57 ug/l). All other stations on the Clark Fork and the comparative rivers, including stations on the Missouri, Yellowstone, Beaverhead and Madison, had average summer nitrate/nitrite concentrations that were less than 50 ug/l. In fact, as can be seen on Figure 9, four sections on the Clark Fork and four of the comparative rivers had very low summer averages (10 ug/l or less).

Two other water quality measurements, total alkalinity and hardness, have been used, usually with limited success, to compare the productivity and/or biomass potential of streams (Hynes, 1976; Beyerle and Cooper, 1960). Generally speaking, streams with higher alkalinity or hardness usually have a higher biologic potential, although the influence of these parameters is

not as clear as has been demonstrated for nitrogen or phosphorus compounds.

Average total alkalinity concentrations at the fourteen Clark Fork River stations are compared to other Montana trout streams on Figure 10. The Beaverhead at Dillon had a higher average alkalinity concentration (189 mg/l) than was found at any station on the Clark Fork. Conversely, two stations on both the Yellowstone and Madison rivers along with Rock Creek had lower alkalinity averages than were found at any of the Clark Fork mainstem stations.

Station comparisons of average total hardness concentrations are displayed on Figure 11. The Clark Fork above the Little Blackfoot River had higher average hardness values (250-272 mg/l) than were found on any of the comparative rivers. From the Little Blackfoot to Bonita, hardness values (222-249 mg/l) were similar to the Beaverhead at Dillon (240 mg/l). From Turah to above the Bitterroot River, hardness averages were similar to the Jefferson at Twin Bridges, the Missouri at Toston and the Little Blackfoot River. Downstream of the Bitterroot, average total hardness concentrations were higher than the average values found at three stations on the Yellowstone and at the Madison below Ennis.

Figure 10. Average Total Alkalinity Concentration in the Clark Fork River (line graphs) versus other Montana Rivers (bar graphs).

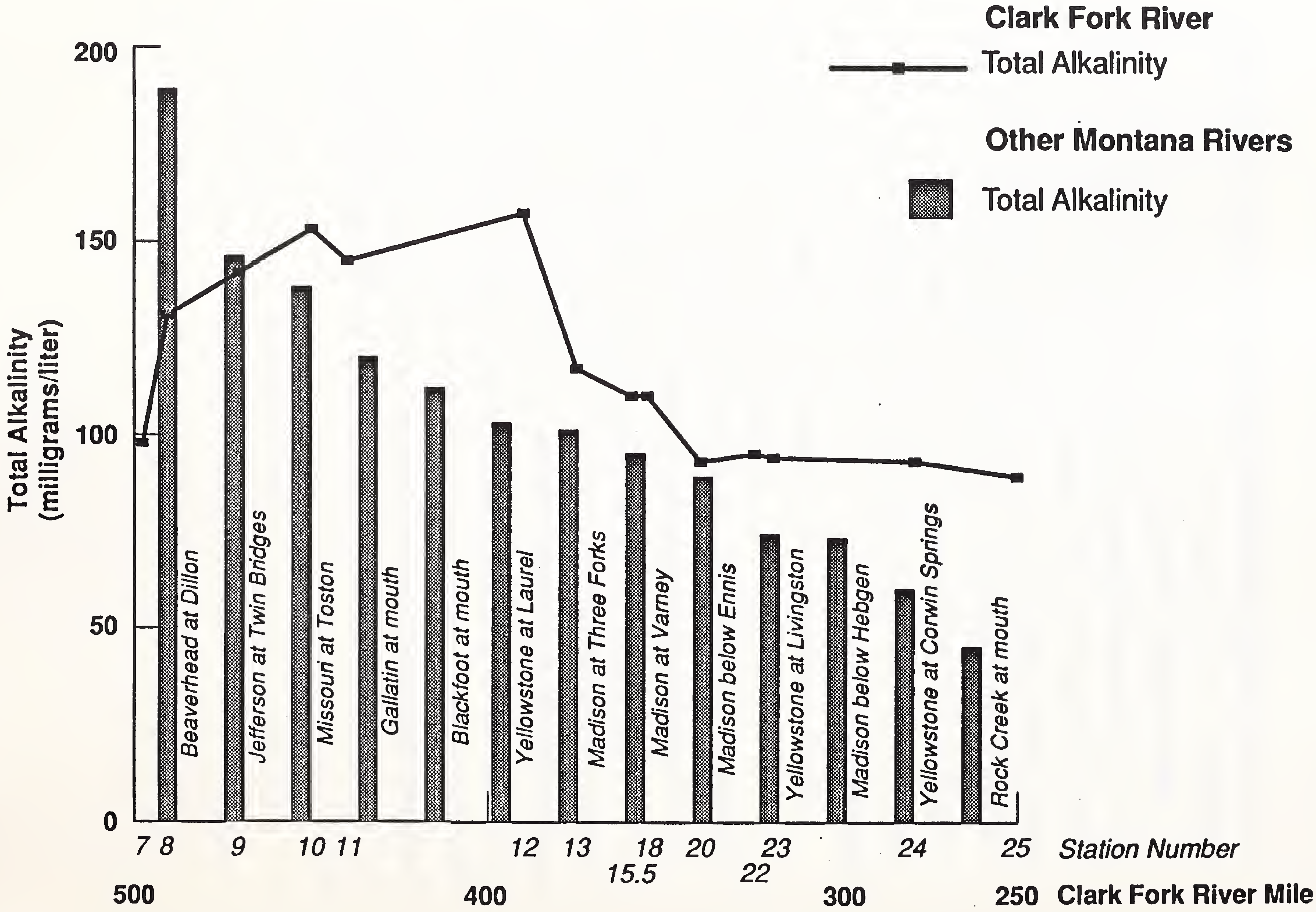
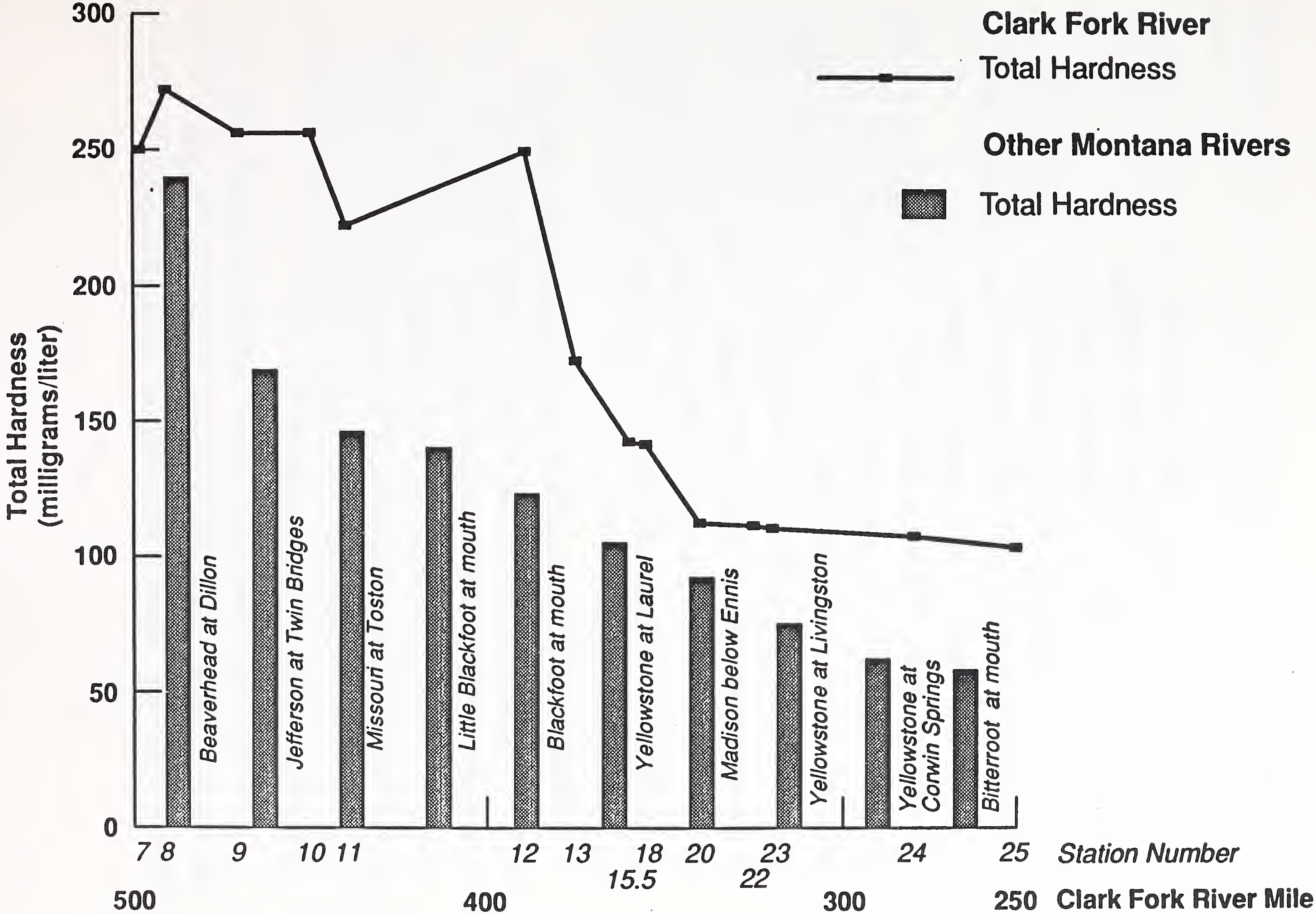


Figure 11. Average Total Hardness Concentrations in the Clark Fork River (line graph) versus other Montana Rivers (bar graph).



V. Discussion

The instream nutrient, total alkalinity and total hardness regimes of the Clark Fork River from its headwaters to the confluence of the Flathead, although widely variable between stations, were generally found to be within the ranges of yearly and summer average concentrations found on other Montana trout streams. Only three minor exceptions were found.

Yearly average total hardness values in the Clark Fork above the Little Blackfoot River were slightly higher than the upper range of concentrations for the other rivers, as were year-round averages for nitrate/nitrite in the river from Deer Lodge to the Little Blackfoot River. Conversely, summer nitrate/nitrite averages for the stations above Missoula and above the Flathead were slightly lower than were found on the other Montana rivers reviewed in this report.

Streams supporting excellent trout populations, like the Gallatin and Madison rivers, were found to have average SRP concentrations similar to the upper Clark Fork. Instream concentrations of this water quality parameter in the river below the Bitterroot, although much lower than were found in the upper river, were still higher than the average concentrations found in the Blackfoot River or Rock Creek.

Throughout the Clark Fork, trout population densities do not appreciably change, even after dramatic changes in average instream nutrient levels. For example, trout population

densities above and below Deer Lodge are about the same, even though the latter station has an average summer SRP concentration 6.5 times higher than above Deer Lodge. Regarding TSIN values, trout populations at Dempsey and above Deer Lodge are similar, despite a five-fold difference in average summer concentrations.

Factors other than instream nutrient concentrations appear to be responsible for the river's depressed trout fishery. Elevated summer water temperatures, caused by dewatering and removal of riparian vegetation, could be somewhat detrimental to trout populations in the Clark Fork River. However, the maximum summer temperatures of 72 to 74°F measured during diel dissolved oxygen studies on the Clark Fork (Kerr, 1987; Watson, 1987; Knudson and Hill, 1978) were cooler than the average summer maximum temperature of 77°F reported by Vincent (1983) for the Madison River below Ennis. This reach of the Madison supports one of the highest trout population densities in Montana.

Instream dissolved oxygen problems on the Clark Fork River are also not too severe. This is largely because of the natural reaeration capacity of flowing rivers (Dobbins, 1964). At monitoring stations immediately above and below Missoula, concentrations of this parameter rarely fell below the State Water Quality Standard of 7.0 mg/l, even during pre-dawn hours when the effects of algal respiration are most notable. In the Clark Fork above Rock Creek, instream dissolved oxygen levels were slightly more problematic for trout, with pre-dawn concentrations dropping to 5.9 mg/l (Knudson and Hill, 1978).

Mining wastes, originating from over a century of massive-scale ore extraction and processing operations in the upper basin, cause the most severe impact to the Clark Fork River's trout fishery. Fine-grained mining wastes that historically have been deposited within the river channel above Milltown (Rice and Ray, 1985) severely impact trout spawning and rearing areas. Periodic episodes of surface water quality degradation occur when stream-side deposits of these wastes are resuspended into the water column during periods of high stream flows and winter freeze-thaw conditions (Knudson, 1984; Phillips, 1985; Johnson and Schmidt, 1988). Other trout-limiting factors include the construction of two railroads, an interstate highway and various agricultural activities within riparian areas above Missoula, which collectively cause significant impacts to channel stability and trout habitat (Peters, 1981). Instream flows are reduced or depleted at several locations between Warm Springs and Drummond (DNRC, 1991), leaving less living area for trout. Sediments entrapped by the hydroelectric dam at Milltown have historically been a source of heavy metals to the river; the dam's structure is also a barrier to trout attempting to move to and from the higher-quality waters of the Blackfoot River (Knudson, 1991).

Below Missoula, water quality impacts associated with mining wastes (heavy metal toxicity) dissipate significantly (Ingman, 1990). But, impacts to trout spawning and rearing areas caused by the deposition of fine sediments remain a problem (Berg, 1989). Dewatering is not a significant problem on the mainstem

below Missoula, but it is on most tributaries. When tributary stream flows are depleted, opportunities are lost for spawning and recruitment that could, in turn, enhance the river's trout population density. Channel stability, morphology and trout habitat in this reach have not been significantly altered by human activities. However, with the exception of the canyon near Alberton, most of the river between the Bitterroot and Flathead has a very low stream gradient, averaging only about five feet per mile (Berg, 1990). This reach contains many deep pools, backwater areas and low-velocity runs. This type of instream habitat is favored by squawfish, a species native to the Columbia Basin that is a formidable predator upon young trout. Squawfish prefer current velocities that are less than one foot per second (Faler, et. al., 1988), while trout prefer velocities 2 to 5 times higher than this rate (Binns and Eiserman, 1979).

The sluggish flow of this reach, especially in its backwaters, also causes more rapid and prolonged elevation of water temperatures. Trout feed and grow best at water temperatures between 7.5°C and 15°C; above 20°C feeding essentially stops (Elliot, 1975). On the other hand, at 20°C, feeding rates of squawfish are three times higher than at 10°C (Beyer, et. al., 1988). Squawfish are also much more tolerant to heavy metal toxicity than are trout, especially to elevated cadmium and zinc levels (Andros and Ganton, 1980).

All of the above factors tend to favor squawfish over trout in this reach of river. This realization tends to dispel an

often quoted misconception -- that this reach of the Clark Fork River is presently unproductive from a fisheries point of view. Yet, anyone who has fished, snorkeled or simply looked into the deep quiet pools of this reach during low water knows that there are lots of big squawfish present. The MDFWP has not conducted population estimates for this species on the Clark Fork or elsewhere, but when or if this ever happens, it is likely that the numbers would rival those for trout in many Montana rivers outside of the Columbia Basin. This is an important point to keep in mind whenever nutrient:fisheries correlations between river systems are discussed.

VI. Conclusion

In the overall scheme of things, the possible effects of changes in nutrient levels pale in comparison to other problems facing the Clark Fork River's trout fishery. Furthermore, even when the present impacts of heavy metal toxicity and sediment deposition, along with trout habitat, spawning and recruitment problems are successfully mitigated, it is improbable that the control of human-caused nutrient sources could ever lead to limitations in trout production. This is true, at least, above the river's confluence with the Flathead. Even after the phosphorus ban, summer and yearly average SRP concentrations in the river above the Flathead were still well above the averages for Rock Creek and the Blackfoot River, streams that support

excellent trout populations. As well, the average summer SRP concentrations at Station 25 (4 ug/l), which was the lowest value found at any location, is still well above the 1 ug/l needed to saturate periphyton growth.

Continuing a program aimed primarily at phosphorus control makes sense based upon the present status of TSIN concentrations and sources in the Clark Fork Basin. Additional reductions in TSIN levels below the confluence of the Blackfoot River could possibly reduce algal primary productivity rates. Whether this reduction would impact benthic invertebrate production and ultimately the trout fishery is uncertain. However, additional lowering of TSIN concentrations, which are frequently below the algal growth saturation value of 50 ug/l, has at least a higher theoretical potential for impacting the trout fishery than does further reduction of instream phosphorus levels. Continued reductions of phosphorus loads at point and non-point sources below the Blackfoot River should continue to help reduce the aesthetic and dissolved oxygen problems associated with accumulations of attached algae without impacting trout production.

At some locations on the Clark Fork River and during certain seasons, Watson (1988) feels that phosphorus or nitrogen, or a combination of both, can be responsible for controlling periphyton growth. In the upper river, where nitrogen often plays an important role in limiting periphyton growth, reducing instream TSIN levels would likely help reduce the occurrence of

nuisance levels of attached algae. Once TSIN sources between Warm Springs and Deer Lodge are better quantified, reductions in human-caused loads may be possible. Meanwhile, phosphorus-control measures at the Deer Lodge WWTP would likely improve nuisance periphyton and dissolved oxygen levels in the reach of river most plagued with these problems. Conversely, from a nutrient-limitation point of view, trout production in the upper river could never be limited by a lack of SRP, even if all human-caused sources of this nutrient were to be controlled. This is because considerable quantities of this nutrient enter the river from natural sources in the reach between the Little Blackfoot and Blackfoot rivers (Ingman, 1991).

Literature Cited

Andros, J.D. and R.R. Garton. 1980. Acute lethality of copper, cadmium and zinc to northern squawfish. EPA-600/J-80-398. Corvallis, OR.

Berg, R.K. 1989. Lower Clark Fork River Fishery Investigation. Proj. No. F-46-R-2. MDFWP. Missoula, MT.

Berg, R.K. 1990. Lower Clark Fork River Fishery Investigation. Proj. No. F-46-R-3. MDFWP. Missoula, MT.

Beyer, J.M., G. Lucchetti and G. Gray. 1988. Digestive tract evacuation in northern squawfish. Can. J. Fish Aquatic Sci. 45 (3) 548-553.

Beyerle, G.B. and E.L. Cooper. 1960. Growth of brown trout in selected Pennsylvania streams. Trans. Am. Fisheries Soc. 89:255-262.

Binns, N.A. and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Tran. Am. Fisheries Soc. 108:215-228.

Bothwell, M.L. 1988. Growth rate responses of lotic periphytic diatoms to experimental phosphorus enrichment: the influence of temperature and light. Can. J. Fish Aquatic Sci. 45:261-270.

Bothwell, M.L. 1989. Limited growth dynamics of lotic periphytic diatom communities: areal biomass and cellular growth rate responses. Can. J. Fish Aquatic Sci. 46:1293-1301.

Cada, G.F., J.M. Loar and M.J. Sale. 1987. Evidence of food limitation of rainbow and brown trout in southern Appalachian soft-water streams. Trans. Am. Fisheries Soc. 116:692-702.

Dobbins, W.E. 1964. BOD and oxygen relationships in streams. Proc. Am. Soc. of Civil Engineers. SA3:55-77.

DNRC. 1991. Upper Clark Fork Basin water reservation applications. Final EIS. Department of Natural Resources and Conservation. Helena, MT.

Elliot, J.M. 1975. The growth rate of brown trout (Salmo trutta) fed on maximum rations. J. Anim. Ecol. 44:805-821.

Faler, M.P., L.M. Miller and K.I. Welke. 1988. Effects of variation in flow on distributions of northern squawfish in

the Columbia River below McNary Dam. N. Am. J. Fish Man. 8 (1) 30-35.

Hadley, W.F. 1989. Survey and inventory of the upper Clark Fork River. Proj. No. F-46-R-1. MDFWP. Deer Lodge, MT.

Hyatt, K.D. and J.G. Stockner. 1985. Responses of sockeye salmon to fertilization of British Columbian lakes. Can. J. Fish. Aquat. Sci. 42:320-331.

Hynes, H.B.N. 1976. The ecology of running waters. Univ. of Toronto Press.

Ingman, G.L. 1990. Clark Fork Basin nutrient pollution source assessment. Second Interim Report. MDHES. Helena, MT.

Ingman, G.L. 1991. Clark Fork Basin nutrient pollution source assessment. MDHES. Helena, MT.

Johnson, H.E. and C.L. Schmidt. 1988. Clark Fork Basin status report and work plan. Office of the Governor. Helena, MT.

Kerr, M.A. 1987. Dissolved oxygen in the Clark Fork River near the Missoula WWTP and the Stone Container Corp. July 8-9 and August 5-6, 1986. MDHES. Helena, MT.

Knudson, K.N. 1984. Preliminary assessment of impacts to the trout fishery--upper Clark Fork River, Montana. Prepared for MDFWP. Helena, MT.

Knudson, K.N. 1991. Effects of Milltown Dam on the Clark Fork River trout fishery and possible mitigative measures. Prepared for MDFWP. Missoula, MT.

Knudson, K.N. and K.E. Hill. 1978. An investigation to define minimum stream flows necessary to sustain the fishery of the upper Clark Fork River. MDFWP. Helena, MT.

Neves, R.J. and G.B. Pardue. 1983. Abundance and production of fishes in a small Appalachian stream. Trans. Am. Fisheries Soc. 112:12-26.

Peters, D. 1981. Western Montana fisheries investigation. Proj. No. F-12-R-31. MDFWP. Missoula, MT.

Phillips, G.R. 1985. Relationships among fish populations, metals concentrations and stream discharge in the upper Clark Fork River. Proc. Clark Fork Riv. Sym. pp. 57-73. MT Bur Mines Geo. Butte, MT.

Rice, P.M. and G.J. Ray. 1985. Heavy metals in flood plain deposits along the upper Clark Fork River. Proc. Clark Fork Sym. pp. 26-45. MT Bur Mines Geo. Butte, MT.

U.S. EPA. 1986. Quality criteria for water. EPA 440/5-86-001. U.S. Environmental Protection Agency. Washington, D.C.

Vallentyne, J.R. 1974. The algal bowl. Dept. of the Environment, Fisheries and Marine Service. Fs 4-31/22. Ottawa.

Vincent, R.E. 1983. Southwest Montana fisheries investigation. Proj. No. F-9-R-28. MDFWP. Bozeman, MT.

Watson, V. 1990. Control of algal standing crop by P and N in the Clark Fork River. Prepared for MDHES. Helena, MT.

Watson, V. 1987. Dissolved oxygen in the middle Clark Fork River, summer 1987. Proc. Mont. Acad. Sci. 49:147-162.

Watson, V. 1988. Clark Fork River nuisance algae study. Prepared for MDHES. Helena, MT.

Appendix A. Period of Record and Number of Samples Used to Compute Parameter Averages for Rivers Other than the Clark Fork

Station	Number of Samples	Period of Record
Soluble Reactive Phosphorus		
Beaverhead at Dillon (Bvhd)	39	1/75 - 10/78
Blackfoot at mouth (Blkft)	47	7-87 - 6/90
Gallatin at mouth (Bal)	13	5/76 - 7/77
Jefferson at Twin Bridges (Jef)	23	2/71 - 1/72
Madison below Ennis (Mad-En)	13	5/76 - 7/77
Madison below Hebgen (Mad-Hb)	13	6/76 - 6/77
Madison at Varney (Mad-Va)	12	6/76 - 7/77
Missouri at Toston (Mo)	36	11/81 - 8/90
Rock Creek at mouth (RCR)	30	7/88 - 6/90
Yellowstone at Corwin Springs (Yel-Cs)	16	2/77 - 9/78
Yellowstone at Laurel (Yel-La)	20	2/77 - 9/78
Yellowstone at Livingston (Yel-Li)	18	2/77 - 9/78
Nitrate plus Nitrite		
Bvhd	40	1/75 - 10/78
Blkft	47	7/87 - 6/90
Little Blackfoot at mouth	30	7/88 - 6/90
Mad-En	7	10/78 - 7/79
Mo	38	9/77 - 9/81
RCR	30	7/88 - 6/90
Yel-Cs	16	2/77 - 9/78
Yel-La	138	2/74 - 9/79
Yel-Li	19	2/77 - 9/78
Total Alkalinity		
Bvhd	43	1/75 - 10/78
Blkft	47	7/87 - 6/90
Gal	13	5/76 - 7/77
Jef	22	2/71 - 1/72
Mad-En	13	5/76 - 7/77
Mad-Hb	13	6/76 - 6/77
Mad-Va	12	5/76 - 7/77
Madison at Three Forks	16	5/76 - 12/77
Mo	40	9/77 - 9/81
RCR	22	4/85 - 10/90
Yel-Cs	15	2/77 - 7/78
Yel-La	19	2/77 - 9/78
Yel-Li	19	2/77 - 9/78

Total Hardness		
Bvhd	43	1/75 - 10/78
Bitterroot at mouth	32	7/87 - 6/89
Blkft	47	7/87 - 6/90
Jef	24	2/71 - 1/72
Mad-En	9	10/78 - 7/79
Mo	39	9/77 - 9/81
Yel-Cs	17	2/77 - 7/78
Yel-La	19	2/77 - 9/78
Yel-Li	18	2/77 - 9/78
Little Blackfoot River at mouth	14	3/74 - 5/80